Conservation Practices in Western Oregon Perennial Grass Seed Systems: I. Impacts of Direct Seeding and Maximal Residue Management on Production

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ABSTRACT

Recent legislative actions addressing concerns about water and air quality have placed restrictions on open field burning and other grass seed production practices. Because of natural resource quality concerns and economic pressures, there is a need to identify production systems that protect natural resources while still providing economic returns to grass seed farmers. A 10-yr field study was conducted at three locations in western Oregon. We compared the effects of direct seeding (DS) with conventional tillage (CT) establishment, combined with maximal (HR) and minimal (LR) residue management, on seed yield, straw phytomass yield, partial budget costs, and estimated soil erosion from perennial ryegrass (*Lolium perenne* L.), tall fescue (*Festuca arundinacea* Schreb.), and creeping red fescue (*F. rubra* L.). Perennial ryegrass (PRG) and tall fescue (TF) seed yields were greater using DS, whereas creeping red fescue (CRF) yields were unaffected. Seed yield from all three crops was unaffected by residue management amount. Both DS and HR reduced soil erosion and cost less to implement than CT and LR by straw baling and removal. Compared with the industry standard practice of LR management plus CT establishment, use of HR combined with DS reduced soil erosion 76.9, 70.2, and 40.0% for PRG, TF, and CRF, respectively. The cost savings using the DS-HR conservation system compared with the CT-LR farm standard were 60, 76, and 84%, respectively. It was also observed that nonmarket opportunities have resulted from implementation of the alternative conservation practices. These research findings document the suitability of DS used in combination with HR in maritime Pacific Northwest region perennial grass seed production systems without needing postharvest straw removal.

O~VER 60% OF THE WORLD~ and 90% of the U.S. supply of temperate forage and turfgrass seed is produced on approximately 187 000 ha in the Pacific Northwest region. Historically, much of the postharvest straw residue from grass seed fields was disposed of using open field burning. Because of air quality and public safety concerns, the grass seed industry has faced increasing legislative pressure since 1971 to ban field burning (Oregon Dep. of Agric., 2004). Final 1991-implemented legislation in Oregon phased down field burning between 1992 and 1998 to 10% of the historic high. Since that time, a rule was implemented in 1997 in Washington State that began curtailing field burning of Kentucky bluegrass seed fields, with a complete ban by 1999 (Hinnman and Schreiber, 2001). A similar burning ban is under con-

sideration for Idaho grass seed production. Widely used agricultural production practices rarely are rapidly phased out of use. Discontinuing a common practice such as field burning in a short time period allows little time to identify economic alternative methods that can be demonstrated to enhance the environment.

Burning in western Oregon seed fields was introduced in 1948 to control diseases that infect grass inflorescences (Chilcote, 1969; Hardison, 1976). Subsequently, it became widely believed that consistent seed yields could not be achieved without burning (Canode and Law, 1975, 1979; Chilcote, 1969; Chilcote et al., 1980; Ensign et al., 1983; Hickey and Ensign, 1983; Young et al., 1984). Only a few reports showed situations where nonburn methods produced results similar to those for burning (Pumphrey, 1965; Rampton and Jackson, 1969; Canode, 1972). Differing results from nonburn management methods have been attributed to differences among crop species and age of the perennial grass seed field stands (Chilcote and Youngberg, 1975; Young et al., 1998).

The phasedown of burning as the dominant straw management practice left Pacific Northwest grass seed growers with 2.5 to 15 Mg ha^{-1} of straw to manage annually (Young et al., 1984). Since the Oregon field-burning phasedown, over 534 000 Mg of straw produced from western Oregon grass seed fields is exported annually and utilized in Asian markets as animal feed (Oregon Dep. of Agric., 2002). Generally, Oregon seed farmers receive little if any income for their straw from brokers who bale and remove the straw at no cost. Washington State growers can sometimes export straw directly to Canadian livestock markets.

The general attitude by Pacific Northwest seed growers toward straw has been that it was a liability and not an asset. It was believed that mechanical straw removal methods could substitute for burning (Chilcote et al., 1983), and while subsequent seed yields were generally inferior, they were better than yields resulting from no straw removal (Chilcote et al., 1978). After the initial public challenges to field burning in western Oregon during the 1970s, research was begun to determine alternative ways to manage the straw. These methods relied on extensive mechanical inputs to remove as much straw as possible and to emulate the effects of open field burning (Young et al., 1994). The approaches investigated included: raking and baling followed by propane burning (Chilcote and Youngberg, 1975; Mueller-Warrant et al., 1995; Young et al., 1999), close mechanical scalping with vacuum removal following raking

Abbreviations: CRF, creeping red fescue; CT, conventional tillage; DS, direct seeding; HR, maximal residue; LR, minimal residue; PRG, perennial ryegrass; RUSLE A, soil erosion estimated by the Revised Universal Soil Loss Equation; TF, tall fescue.

and baling (Young et al., 1984; Mueller-Warrant et al., 1995), and raking and baling followed by flailing of the remaining plant crowns (Young et al., 1984; Mueller-Warrant et al., 1995).

An alternative but limited use method at that time was to finely chop the entire straw residue load back onto the field using tractor-powered flails (Mueller-Warrant et al., 1995; Young et al., 1999). This operation reduced the long straw into short, fractured pieces that decomposed between the grass seed rows during the relatively mild and wet winters common to western Oregon.

At the time of the field burning phasedown, little or no DS practices had been used to establish perennial grass seed crops. Scant knowledge existed regarding the impact of DS rotation crops into grass seed stubble following straw removal (Young and Youngberg, 1996a), and virtually nothing was known about the impact of full straw management used in conjunction with DS.

Direct seeding and returning residue to fields are considered to be conservation practices beneficial to water quality that reduce erosion and transport of sediment to surface waters. In the Willamette and Puget Sound Valleys Major Land Resource Area (MLRA), estimated soil losses of 2.1 Mg ha^{-1} yr^{-1} are associated with water erosion from perennial grass seed crops while corresponding losses from cereal production account for 4.5 Mg ha^{-1} yr^{-1} (USDA-NRCS, 1990). The average soil erosion amount from agricultural lands west of the Cascade Mountains is 2.2 Mg ha^{-1} yr^{-1} compared with 4.1 Mg ha^{-1} from the arid eastern side of the Cascades. As an estimate for a native benchmark condition, USDA Conservation Reserve Program lands west and east of the Cascades are 0.42 and 0.82 Mg ha^{-1} sediment yr^{-1}, respectively (USDA-NRCS, 1990).

This research was conducted over a 10-yr period using three soil conditions typical of the Pacific Northwest temperate marine ecoregion where perennial grass seed crops are grown. The impacts of implementing DS combined with maximal postharvest straw management without burning on seed yield, straw phytomass production, partial budget establishment costs, and estimated soil erosion was determined. Nonmarket opportunities resulting from implementation of the alternative conservation practices by farmers were also recorded. These conservation practices were considered as alternatives to traditional systems that use tillage to establish stands and burning or baling to remove straw after harvest.

MATERIALS AND METHODS

Field Experiments

The research was conducted from 1992 to 2001 at three sites in the Willamette Valley, OR that represented contrasting physical environments suitable for perennial grass seed production in the Pacific Northwest temperate marine ecoregion. One species suited to each of the three growing conditions of each site was used: (i) PRG 'Riviera' and 'Prana' on a poorly drained Amity silt loam (fine-silty, mixed, mesic Argiaquic Xeric Argialbolls) in Linn County (Linn) on a commercial farm (44°28′56″ N, 123°11′01″ W; 76 m elevation); (ii) TF 'Titan' and 'Hound dog' on a poor to moderate drained Woodburn silt loam (fine-silty, mixed, mesic Aquultic Argixe-

rolls) grown in Benton County (Benton) on the Hyslop Research Farm (44°38′01″ N, 123°12′01″ W; 70 m elevation); and (iii) CRF 'Jasper' and 'Bridgeport' on a Nekia silty clay loam with 2 to 12% slopes (clayey, mixed, mesic Xeric Haplohumults) in Marion County (Marion) on a commercial farm (44°56′24″ N, 123°45′19″ W; 236 m elevation).

General Plot Layout

Twenty-four (Linn and Benton) and 28 (Marion) plots approximately 18 m wide by 34 m long were prepared in autumn 1991. Grass seed stands of the representative species were already being produced at the three sites before the start of the experiment. The plots were arranged as four replicate blocks with six plots per block at Linn and Benton and seven plots per block at Marion. The common treatments to the three sites were comparisons of (i) CT versus DS establishment and (ii) minimal versus maximal postharvest straw amounts returned to the field. Some crop rotations grown over the 10-yr period were repeated grass seed crops (continuous grass) while others had nongrass crops included in the rotation.

A perennial grass seed crop sequence was defined as the consecutive multiple seed harvest years from the period of establishment to the time of destroying the stand and planting of another grass seed crop or a nongrass seed rotation crop. The number of harvest years in a sequence was either 2 or 3 yr. All repeated treatment sequences and harvest-year combinations had high and low straw residue amount comparisons. There were four replicate blocks for all sequences. A detailed description of the crops grown in rotation on each plot at each location during the 10-yr period is available on request.

Season of planting (autumn or spring) for all crops was based on general industry practice. Among the three crops, PRG can be planted in autumn and produce a full seed crop the following summer. Both TF and CRF are planted in spring and will have the first seed crop harvested 15 mo later in summer. The rotation crops used at Linn were white clover (*Trifolium repens* L.) grown for seed, meadowfoam (*Limnanthus alba* Benth.), and spring wheat (*Triticum aestivum* L.). At Benton, red clover (*T. pratense* L.) grown for seed, meadowfoam, and winter or spring wheat were planted. At Marion, red clover for seed, meadowfoam, or winter or spring wheat were grown. Red and white clovers were planted in the spring and meadowfoam in the autumn.

The establishment method treatments were either applied to entire 18-m-wide plots (in which case, two 18-m-wide plots were used for the comparison), or in some cases, the establishment method treatments were applied to the two 9-m-wide halves of a 18-m-wide plot. Assignment of treatments was at random for both situations. Each 34-m-long plot was split into two 17-m-long subplots with one subplot having all of the straw returned after harvest and the other half having the straw removed by raking and baling (full or minimal straw management treatments, respectively). The residue amount treatment was assigned at random after the first time grass was grown and harvested from a plot.

All treatments were investigated without burning the grass straw after seed harvest. The grass seed crops and treatment combinations selected were used as examples and not meant to represent all production options or conditions available to farmers in the western Oregon region.

Production Practice Operations

To facilitate the application of tillage treatments to the research plots, a tractor-powered rotor-tiller (3 m wide) mounted on a three-point hitch was used to simulate the multiple tillage

operations used by farmers when preparing the soil for planting (CT establishment). Following tillage, the plots were rolled twice to firm the seeding bed for planting. For the DS plots, nonselective herbicide N-(phosphonomethyl)glycine was used to control volunteer crop seedlings and weeds before planting. After an initial 2-yr assessment of direct-seed drills, it was determined that both direct-seeded and conventional disturbance plots could be planted with commercial double-disc openers (John Deere, Moline, IL) attached to a Hege 80 plot-style planter frame (Hege Seedmech, Colwich, KS). Grass planting depth was typically 10 mm. All perennial grass plantings were evaluated by each replicate block for stand establishment completeness. Those blocks that had noticeable emergence skips after planting (total area of patches > 20% of the plot area) had those areas overseeded by a single-row, hand-pushed planter the next planting season. All other production practices including seeding rates, weed control, fertilization, and insect and disease control practices, as needed, were similar to those of commercial producers in each area. All other production practices were the same regardless of establishment or straw residue management methods. All pesticides applied were according to approved recommendations.

The grasses were harvested for seed and total phytomass yield by cutting into windrows per farmer specifications for timing of harvest using a 2-m-wide plot-scale swather built from a 4-m commercial-sized unit (John Deere, Moline, IL). Two replicate lengths of windrow approximately 3 m long were gathered by hand from each treatment combination and placed in burlap bags for drying. The portions of the windrows that remained after sampling were harvested to remove the seeds using a commercial combine fitted with a windrow pick-up head typically used for grass seed crops (John Deere, Moline, IL). Similar methods were employed for the nongrass seed rotation crops.

A custom-made flail similar to the kind used by farmers in the region (Rears Manufacturing, Eugene, OR) was used to complete the residue amount treatments after harvest. The minimal straw residue amount treatment had the straw removed by baling. The remaining full and minimal straw amounts left on the subplots were chopped twice or once, respectively. The chopped residue typically was spread between the planting rows by the flail operation. If the straw was not evenly distributed, further spreading was done by hand using rakes. Only the grass seed and wheat crops had the two residue management treatments applied. All residue amounts produced by the meadowfoam, red clover seed, and white clover seed crops was returned to the plots.

Grass seeds were threshed from the total harvest phytomass after drying for 24 h at 30°C in a gas-heated walk-in drying room. Seeds were separated from the straw using a custom-built 1-m-wide belt thresher. Seed cleaning was done over screens in a Clipper M2B seed cleaner (A.T. Ferrell and Co., Saginaw, MI) to allow measure of clean seed yield. Straw phytomass produced by the crop was calculated by subtracting seed yield from the total harvested phytomass.

Conservation Practice Effects

Partial Budget Economic Analysis

A partial budget approach (Carkner, 2005) was used to compare cost differences among the production practices used to prepare fields for planting (establishment following CT and DS following nonselective herbicide applications) and post-harvest straw residue management (LR and HR amounts remaining). Because a rotor tiller was used to simulate tillage in our plots, a telephone census of six farmers was conducted to determine the typical kinds and number of tillage operations used by farmers when preparing the soil for

ations (plow, disc, harrow, and roll) needed to prepare seed fields for each of the three species when using CT.

The estimated costs for preparing PRG, TF, and CRF fields for planting by CT were U.S. $155.6, $155.6, and $464.4 ha^{-1}, respectively. The same implement, tractor, and spray costs for all crops were assumed. The cost of the nonselective herbicide used in field preparation for DS was based on farmer cost in the region ($10.46 L^{-1}). The volumes of nonselective herbicide required to substitute for tillage in PRG, TF, and CRF were 3.5, 8.2, and 5.8 L ha^{-1}, respectively.

Costs for LR management following harvest were raking and baling of the straw in the field ($32.97 ha^{-1}), hauling and stacking baled straw from the field ($13.39 ha^{-1}), and a single flailing of plant crowns and remaining residue after hay removal ($5.83 ha^{-1}). The cost for the maximal straw amount treatment was based on two flail operations with none of the straw removed from the field ($11.66 ha^{-1}). All other operations used to produce the crops, apart from establishment and residue management, were considered the same. Costs of operations were estimated from Oregon State University Extension Enterprise Budgets, University of California Extension Cost and Return Budgets, and the farmer census. Value to the farmer for clean seed of PRG, TF, and CRF was $1.36, $0.99, and $1.21 kg^{-1}, respectively, based on an industry census estimate.

Nonmarket valued costs for purchased labor use and recreation opportunities were estimated by discussing with a panel of farmers outcomes they have observed since implementing the alternative conservation technologies. These are not willingness-to-pay estimates as used in contingent valuations (Cameron et al., 2002). These qualitative findings are reported as personal communications. Including both market (U.S. dollar) and nonmarket valuations in production system assessments not only estimates the impacts of implementing conservation practices, but also provides an opportunity for comparison of human effect impacts.

Estimated Soil Erosion

The Revised Universal Soil Loss Equation (RUSLE) using RUSLE 1.06c software was used to estimate the annual amount of soil erosion (RUSLE A). Weather data from the 30-yr average from stations located at Hyslop Farm near Corvallis, OR (for Benton and Linn) and Silverton, OR (for Marion) were used. Soil data for the three research sites were obtained from USDA Natural Resources Conservation Service (USDA-NRCS) soil surveys. The slope for each site was measured using a clinometer (Haglof, Madison, MS). For Linn and Benton, a 305-m length segment with a 1% gradient was used. A 152-m length segment with a 4% gradient was used for Marion. Estimated operations and their timing were based on the census of local growers. Residue management and tillage operations were begun immediately after seed harvest. Estimates of crop cover and phytomass accumulation through time for use in RUSLE were based on literature (Chastain and Grabe, 1988a; Velloza, 1998) and field observations. The crop production calendar for RUSLE was based on a 1 November start date. The specific RUSLE parameters used are available on request.

Based on the actual amounts of straw phytomass measured from all plots for each crop over the 10-yr period, a range of the straw input amounts (data not shown) was used to calculate RUSLE A based on the site characteristics and crop operations used for each site. The 10-yr median amount of straw produced by each crop (8500, 12 000, and 7000 kg ha^{-1} for PRG, TF, and CRF, respectively) was multiplied by the 78.5% (Chastain et al., 1995) to estimate the amount of straw removed by baling. Amounts of residue remaining in the min-

imal straw management treatments were 1830, 2580, and 1505 kg ha^{-1} in PRG, TF, and CRF, respectively.

Experimental Design and Analysis

Experimental Design and Analysis Overview

A meta-analysis approach was used to synthesize the results from 23 replicated experiments conducted at the three locations over the 10-yr period. A summary of the experiments used in the meta-analyses, referred to as primary experiments, is given in Table 1. Meta-analysis is a statistical synthesis method typically used to combine the findings from a number of different studies in published literature (Rosenberg et al., 2004). Meta-analysis procedures are used to estimate overall treatment effects, determine the homogeneity among the studies that will be combined, and calculate the summary statistics. Since all of the data used in our meta-analyses came from original data, measures of treatment effects and variance did not have to be estimated from reported literature.

Three kinds of studies (described below) were formed from the primary experiments and used in the meta-analyses for each grass species. Statistical power was increased for testing treatment effects that otherwise had a limited number of degrees of freedom in any single primary experiment (such as one degree of freedom for either the two establishment methods or two residue management amount treatments), with only four degrees of freedom in the error term. Combining studies tripled the error term number of degrees of freedom in the meta-analysis.

Primary Experiments

For each of the three crops, there were two repeated multiple harvest-year sequences arranged in a balanced complete factorial design with establishment methods, seed harvest years, and residue management amount (Table 1, Exp. 1). An initial analysis of variance (ANOVA) was done as a split-plot-type randomized complete block design with the

hierarchy: sequences (S) and blocks (B) > seed harvest years (Y) > establishment method (E) > residue management (R). The model for this design was

$$y_{ijkl} = \mu + S_i + B_j + SB_{ij} + \delta_{(ij)} + Y_k + SY_{ik} + SBY_{ijk}$$
$$+ \gamma_{(ijk)} + E_l + SE_{il} + BE_{jl} + YE_{kl} + SYE_{ikl}$$
$$+ SBE_{ijl} + BYE_{jkl} + SBYE_{ijkl} + \omega_{(ijkl)} + R_m$$
$$+ SR_{im} + BR_{jm} + YR_{km} + ER_{lm} + SBR_{ijm}$$
$$+ SYR_{ikm} + SER_{ilm} + BYR_{jkm} + BER_{jlm}$$
$$+ SBYR_{ijkm} + SBER_{ijlm} + BYER_{jklm}$$
$$+ SBYER_{ijklm} + \varepsilon_{(ijklm)}$$

The restrictions on randomization were represented in the model by: $\delta_{(ij)}$ = the first restriction error, $\gamma_{(ijk)}$ = the second restriction error, and $\omega_{(jkl)}$ = the third restriction error. The mean square (MS) for the interaction preceding each restriction error was used to test the preceding treatment main effect and its interactions. The MS for $SBYER$ was used to test residue treatment and its interactions.

Also for each of the three crops, there were multiple harvest-year unpaired sequences for DS (Exp. 2) and CT (Exp. 3) treatments (Table 1). All multiple harvest-year unpaired sequences for DS and CT treatments were combined and analyzed as an unbalanced split-plot-type randomized complete block design with the analysis hierarchy: harvest year > blocks > establishment method > residue management. The model for this design was

$$y_{ijkl} = \mu + Y_i + B_j + YB_{ij} + \delta_{(ij)} + E_k + YE_{ik}$$
$$+ BE_{jk} + YBE_{ijk} + \gamma_{(ijk)}R_l + YR_{il} + BR_{jl}$$
$$+ ER_{kl} + YBR_{ijl} + YER_{ikl} + BER_{jkl}$$
$$+ YBER_{ijkl} + \varepsilon_{(ijkl)}$$

The restrictions on randomization were represented by: $\delta_{(i)}$ = the first restriction error and $\gamma_{(ij)}$ = the second restriction error.

Table 1. A summary of three kinds of primary experiments conducted at each of three locations in western Oregon from 1992 to 2001 that were used to estimate by meta-analysis the impacts of direct seeding and maximal residue management on perennial ryegrass, tall fescue, and creeping red fescue grass seed yield and straw phytomass production.

| | Locations (counties), crops, and experiments† | | | | | | | | |
| | Linn perennial ryegrass | | | Benton tall fescue | | | Marion creeping red fescue | | |
Production conditions	1	2	3	1	2	3	1	2	3
Repeated sequences‡				Seed harvest years§					
1	1998–2000	1995–1996	1993–1995	1997–1998	1995–1996	1993–1994	1993–1994	1993–1994	1995–1996
2	1999–2001	1998–2000	1994–1996	2000–2001	1996–1998	1993–1995	2000–2001	1993–1994	1996–1997
3		1999–2001	1998–2000					1998–2000	1996–1998
4									1997–1999
Primary experiments:	2	3	3	2	2	2	2	3	4
Sequences × harvest years:	6	8	9	4	5	5	4	8	10
Prior crop in rotation:¶	MF–MF	WC–MF–MF	G–G–G	G–G	RC–G	G–G	G–G	G–G–RC	RC–RC–G–G
Establishment method:#	both	DS	CT	both	DS	CT	both	DS	CT
Residue management:††	both	both	both	both	both	both	both	both	both

† Descriptions of the three kinds of primary experiments conducted at each of the three locations: Experiment 1, complete factorial in a balanced split-plot-type design testing harvest years, establishment methods, and residue amounts; Experiment 2, complete factorial in an unbalanced split-plot design containing only direct-seeded establishment method with contrasting residue amounts; and Experiment 3, complete factorial in an unbalanced split-plot design containing only conventional tillage establishment method with contrasting residue management amounts.

‡ The number of the repeated multiple seed year sequences within one of the three kinds of experiments at each of the three locations. The three studies used in the meta-analyses for each grass were constituted by using the primary experiments shown in Repeated Sequences 1 and 2 in Experiment 1 and pooling the primary experiments from Experiments 2 and 3.

§ These are the ranges of the seed harvest years for the grass seed crop within a sequence.

¶ Indicates the prior crop in rotation with the grass seed crop with: G, same-species grass seed crop; MF, meadowfoam; RC, red clover seed; and WC, white clover seed. The order of the crops shown corresponds with the seed harvest years for the repeated grass seed crop sequences given above.

# Indicates the establishment methods used: CT, crop established by conventional tillage; DS, direct seeding; or both, both CT and DS used.

†† Both: indicates that all treatment combinations within the three kinds of primary experiments contained both high and low residue management amount treatments.

The MS for the interaction preceding each restriction error was used to test the preceding treatment main effect and its interactions. The MS for YBER was used to test residue treatment and its interactions.

Meta-analyses

For each of the three grasses, the two repeated multiple harvest-year sequences from Exp. 1 and the combined unpaired DS and CT primary experiment sequences used as the three studies combined in the meta-analyses. The meta-analyses used an unbalanced ANOVA to determine the effects of: (i) harvest year, (ii) DS and CT establishment, and (iii) HR and LR management on seed yield and phytomass production. Each crop was analyzed separately because an initial analysis showed significant interactions for most independent variables with the crop variable. The three studies were analyzed as split-plot randomized complete block designs with the hierarchy: $B > Y > E > R$. The model for this design was

$$y_{ijkl} = \mu + B_i + \delta_{(i)} + Y_j + BY_{ij} + \gamma_{(ij)} + E_k + YE_{jk}$$
$$+ BYE_{ijk} + \omega_{(ijk)} + R_l + YR_{jl} + ER_{kl}$$
$$+ YER_{jkl} + BYER_{ijkl} + \varepsilon_{(ijkl)}$$

The restrictions on randomization are represented by: $\delta_{(i)} =$ the first restriction error, $\gamma_{(ij)} =$ the second restriction error, and $\omega_{(ijk)} =$ the third restriction error. The MS from the *BYER* interaction was used to test the main and interaction effects sources of variation.

Results from the meta-analyses of the three grasses were compared for general agreement with the results from the initial primary experiment analyses (results not shown). The results presented are from the meta-analyses. To determine the homogeneity among the studies (Rosenberg et al., 2004) and justify the fixed model pooled error variation used to test treatment differences in the meta-analysis, the error variances from the three combined studies used in the meta-analysis were examined using the Bartlett homogeneity test (Anderson and McLean, 1974, p. 20). The critical χ^2 value used to test homogeneity was from $P \le 0.001$ with two degrees of freedom. Since none of the compared variances significantly deviated from homogeneity, no weighted adjustment of the means was required when comparing means. Fisher's protected least significant difference was used for mean separations. The results from the meta-analyses are summarized in Table 2.

RESULTS AND DISCUSSION

Crop Growth Variability and Stand Age Effects

Annual average seed and straw phytomass yields generally varied among years for all three crops over the 10-yr period of the study (Table 3). Annual variation was not related to any single climatic variable [e.g., annual precipitation: $r = 0.52, 0.47$, and 0.09 for seed yield; $r = 0.10, 0.63$, and 0.45 for straw phytomass from PRG, TF, and CRF, respectively; $P > 0.05$ for all].

The relationships between seed and straw yields with increasing stand age were different among the three grasses and differed within grasses by the age of the stand (Table 4). The correlations for seed yield with the amount of straw produced were very low ($r = 0.24, 0.31$, and 0.44 for PRG, TF, and CRF, respectively; $P \le 0.001$), indicating that factors other than total straw phytomass affected seed yield.

The amount of PRG seed produced was greatest in the first harvest year while the amounts of straw produced tended to be greater after the first seed production year (Table 4). Since PRG is planted in the autumn, there is a relatively short period for growth from planting time to harvest the following summer, with most growth occurring in spring as temperatures and daylength increase. Seed yield decreased with each successive harvest years.

Tall fescue, on the other hand, did not have seed yield decline until the third harvest year, but the amounts of straw produced declined each successive year. Tall fescue can develop rapidly like PRG when planted in autumn but cannot produce adequate numbers of growing points to produce a full seed crop the following summer. As a result, most TF fields are planted in the spring and the first seed crop harvested 15 months after planting.

Creeping red fescue seed yield declined in the third harvest year with greater straw production during the second and third production years than in the first. Decreasing CRF seed yields with increased stand age was probably a function of the stand becoming sod-bound and a resulting decrease in the number of reproductive growth sites (Chastain and Grabe, 1988b; Fairey and Lefkovitch, 1996; Young et al., 1998) compared with

Table 2. Meta-analysis† analysis-of-variance results for perennial ryegrass, tall fescue, and creeping red fescue grown at three locations in western Oregon from 1992 to 2001 to determine the effects of conservation practices on seed yield and straw phytomass production.

| | Locations (counties)/crops | | | | | |
| | Linn/perennial ryegrass | | Benton/tall fescue | | Marion/creeping red fescue | |
Production effect	Seed yield	Phytomass	Seed yield	Phytomass	Seed yield	Phytomass
	significance level					
Harvest year (Y)	**	***	**	***	***	***
Establishment (E)	*	ns‡	**	ns	ns	ns
Y × E	ns	ns	ns	ns	ns	**
Residue (R)	ns	ns	ns	ns	ns	ns
Y × R	ns	ns	ns	ns	ns	ns
E × R	ns	ns	ns	ns	ns	ns
Y × E × R	ns	ns	ns	ns	ns	ns

* Significant at $P \le 0.05$.
** Significant at $P \le 0.01$.
*** Significant at $P \le 0.001$.
† The meta-analysis was conducted by using three studies constituted from the primary experiments shown in Repeated Sequences 1 and 2 from Experiment 1 and pooling the primary experiments from Experiments 2 and 3 as shown in Table 1.
‡ ns, not significant at $P \le 0.05$.

Table 3. Mean annual precipitation and average yield and straw phytomass production for perennial ryegrass, tall fescue, and creeping red fescue grass seed at three locations in western Oregon from the 1993 to 2001 harvest years.

Location,† crop, and variable	Harvest year								
	1993	1994	1995	1996	1997	1998	1999	2000	2001
Hyslop Farm, Corvallis, OR									
Precipitation, mm‡	646	455	725	971	668	816	801	612	289
Perennial ryegrass									
Seed yield, kg ha⁻¹	1420	743	758	1377	–§	1455	1512	1533	1347
Straw phytomass, kg ha⁻¹	6204	11 178	7061	9021	–	6088	8737	8906	8349
Tall fescue									
Seed yield, kg ha⁻¹	1084	875	801	1695	1074	861	–	1196	1798
Straw phytomass, kg ha⁻¹	19 866	10 789	11 253	13 571	12 504	8427	–	8368	11 752
Silverton, OR									
Precipitation, mm‡	730	553	695	996	896	784	869	690	432
Creeping red fescue									
Seed yield, kg ha⁻¹	590	501	329	923	430	503	666	357	1348
Straw phytomass, kg ha⁻¹	2365	7129	7402	8376	7989	5513	8864	5723	8497

† National Weather Service data station.
‡ Total amount for 1 January to 31 July.
§ Indicates no grass seed plots harvested in this year.

plants in stands that had been burned (Chastain et al., 1995) or had rhizomes removed by aggressive mechanical means (Meints et al., 2001).

Seed yield decline with increasing stand ages and the number of harvest years that a perennial grass seed crop remains in production has practical implications. Seed growers desire to leave established stands in for as long as possible to increase establishment costs amortization. Loss of income for the 15 months when spring-planted TF and CRF does not produce a crop increases the need for longer rotation sequences to recover establishment costs. The economics of the trade-offs between seed yield decline with increasing stand ages and costs of establishment need to be considered.

Direct-Seeding Establishment

Perennial ryegrass and TF average seed yields were greater when using DS than CT (Table 4). Creeping red fescue seed yield (averaged over a 3-yr sequence) was the same when comparing DS with CT establishment. There was generally no affect of establishment method on the amount of straw phytomass production (Table 4). Only in CRF was first harvest-year straw phytomass production reduced with DS compared with the harvest year and establishment treatment combinations (Table 5). The reduced first harvest-year straw amount did not affect CRF seed yield.

Maximal Residue Management

Across all stand ages and establishment methods, HR management using full straw chop-back did not adversely affect grass seed yield or the amounts of total straw phytomass produced in any of the three grass seed systems (Table 2). Even though grass seed yields tended to decline with increasing stand age for all three species (Table 4), seed yield was unaffected by the amount of straw residue remaining in these nonburned systems. Implementation of HR management did not cause a more rapid decline in seed yield compared with when residue is removed. Similar findings have been reported for TF and CRF grown in Canada (Fairey and Lefkovitch, 1996). The absence of seed yield decline from returning HR amounts to the seed field after harvest agrees with the general conclusions of Young et al. (1999), who showed that flail chopping could be as effective as postharvest residue burning of specific cultivars of TF and PRG. Our findings also describe the suitability of combining DS establishment with HR management for Pacific Northwest perennial grass seed cropping systems without burning.

Table 4. Comparisons of direct seeding with conventional tillage establishment methods and residue management amount on seed yield and straw phytomass production in three perennial grass seed systems in western Oregon.

Crop	Establishment method			Harvest year			
	Direct	Tillage	P	One	Two	Three	P
Seed yield	—— kg ha⁻¹ ——			—— kg ha⁻¹ ——			
Perennial ryegrass	1466	1273	*	1468a†	1306b	1319b	**
Tall fescue	1429	1123	**	1343a	1315a	847b	**
Creeping red fescue	618	616	ns‡	637a	677a	396b	***
Straw phytomass							
Perennial ryegrass	8309	8463	ns	7664c	9190a	8302b	***
Tall fescue	12 283	12 870	ns	13 918	12 063b	9266c	***
Creeping red fescue	5889	6830	ns	4937b	7537a	7269a	***

* Significant at P ≤ 0.05.
** Significant at P ≤ 0.01.
*** Significant at P ≤ 0.001.
† Means within rows (species) followed by the same letter are not significant at P ≤ 0.05.
‡ ns, not significant at P ≤ 0.05.

Table 5. Effects of seed harvest year and establishment method on creeping red fescue seed yield and straw phytomass production in Marion County, OR.

Establishment method	Seed yield			Straw phytomass		
	Harvest year			Harvest year		
	One	Two	Three	One	Two	Three
	Mg ha^{-1}					
Direct seeding	599	668	389	3228b†	6362a	7441a
Conventional tillage	668	634	404	6362a	7210a	7097a
Harvest year average	637 a	677 a	396 b	4937b	7537a	7269a

† Means within rows and columns for establishment method × harvest year interactions and within rows for harvest year average effects followed by the same letter are not significant at $P \leq 0.05$.

Assessing Conservation Practice Impacts

Partial Budgets Analysis

Because DS generally resulted in no adverse affect on seed yield, lower establishment costs for the three grass species systems should increase net farm income in all cases. A partial budget analysis of establishment costs (Fig. 1) showed CRF system had the greatest reduced cost of establishment using DS ($399.10 ha^{-1}) compared with the lower reduced costs of establishment for PRG ($114.70 ha^{-1}) and TF ($65.80 ha^{-1}) systems. The greatest single expense in the no-tillage system was the cost of the nonselective herbicide needed to kill the established perennial grass seed stands when changing crops. Greater amounts of herbicide were required for each of the three crops (TF > CRF > PRG) and accounted for the differences in DS establishment costs.

In contrast to DS, the high costs for CRF establishment using CT are due to as many as 15 or more disturbance practices applied from after the time of July harvest in the last harvest year, until winter precipitation prevents further operations to kill the previous stand rhizomes before another grass seed crop can be planted (B. Jaquet, personal communication, 2003). Tillage operations are resumed in spring when weather allows final preparation for spring planting. Fields prepared for PRG and TF require fewer tillage operations for planting because of the relative ease to kill these crops with tillage.
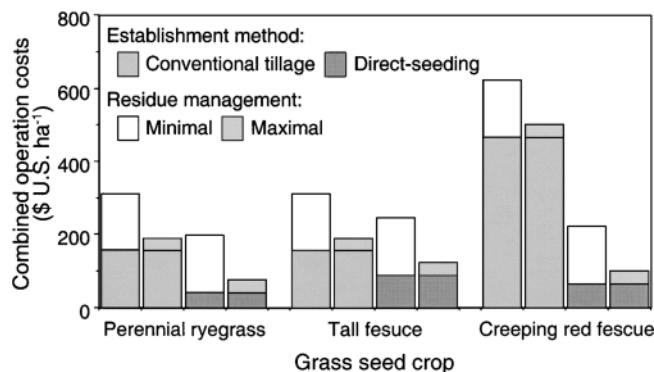

Fig. 1. Partial budget comparisons of the combined costs of establishment and residue management for three perennial grass seed crops grown in western Oregon using: (i) conventional tillage and direct seeding combined with (ii) minimal and maximal residue management. Perennial ryegrass, tall fescue, and creeping red fescue were grown in Linn, Benton, and Marion Counties, respectively.

The cost of removing straw after raking and baling followed by a single flail chop is more expensive than the typical HR management practice of twice flail chopping the straw ($52.19 vs. $11.66 ha^{-1}). However, seed growers who choose low residue management generally do so at no expense because brokers who market the straw bear all straw removal expenses. The cost savings using a DS with HR management conservation system were 60, 76, and 84%, respectively compared with the farm standard using CT and low residue by straw burned or removed after baling.

Estimated Soil Erosion

The conservation benefits of grass seed straw have been only recently recognized (Gohlke et al., 1999). Establishment and residue management practices were assessed for their estimated impact on annual soil erosion (RUSLE A) using the median LR and HR amounts in CT and DS establishment treatments (Fig. 2). Average soil erosion amounts for PRG, TF, and CRF production systems for the rotation cycle including establishment were 0.92, 1.29, and 4.67 Mg ha^{-1} yr^{-1}. Once perennial grass seed crops have become established following planting (Harvest Years 2 and-3), estimated annual erosion amounts are minimal, being less than 0.05, 0.08, and 0.18 Mg ha^{-1} yr^{-1} for PRG, TF, and CRF, respectively (Fig. 2). Changing from CT to DS reduced estimated erosion amount, especially during the period of re-establishment of the crop (Seed Year 0 and 1). Further reductions in soil erosion resulted from introduction of HR amounts, with a greater conservation effect realized in DS compared with CT establishment systems. Introducing HR management with DS reduced RUSLE A erosion 76.9, 70.2, and 40.0%, respectively, compared with the industry standard CT-LR system. Interestingly, when using DS with either LR or HR management, the amount of erosion during the establishment period (period with greatest annual soil erosion amount) is less than the sequence-long average amount for the standard industry practice of CT with LR management (Fig. 2).

Because perennial grass seed fields are only tilled every 3 to 5 yr when establishing new stands, soil erosion amounts are relatively low compared with annual crops (unpublished data, 2004). Introduction of conservation practices such as DS or HR management should reduce erosion losses further, exceeding average estimates for lands under the USDA Conservation Reserve Program in the same part of the region (USDA-NRCS, 1990).

Farmer Implementation and Outlook for Conservation Systems

At this time, HR management is more widely implemented by farmers on a larger scale than DS. However, a majority of grass seed growers (80–85%) have as much straw as possible removed by baling on the 165 000 ha of PRG and TF fields that are not burned. This is in contrast to a majority of the 5600 ha of CRF seed produced on highly erodible hills that is burned annually (Young, 2003).
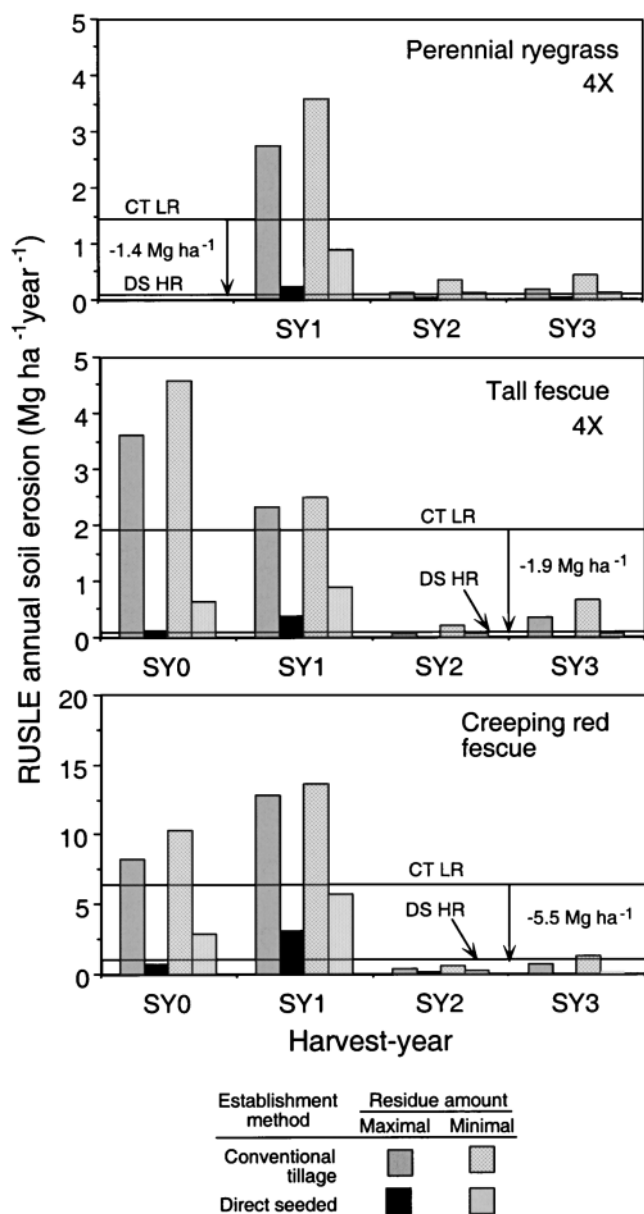
Fig. 2. Comparison of establishment methods, amounts postharvest straw returned to fields, and times from planting on estimated annual soil erosion amount for three perennial grasses grown for seed in western Oregon. Soil erosion is estimated by the Revised Universal Soil Loss Equation (RUSLE 1.06c software). The horizontal lines labeled CT LR and DS HR indicate the average annual soil erosion amount for a monoculture grass seed crop using conventional tillage–low residue and direct seeded–high residue treatment combinations, respectively. Indicated by the arrow is the average annual reduction in soil erosion from implementing DS HR. Note: the scale difference for creeping red fescue compared with the two other grasses. SY, seed year.

Those growers using HR management perceive a benefit to returning organic matter back to their fields. Once alternative herbicide strategies were identified (Mueller-Warrant et al., 1995), emerging weed control problems associated with nonburn culture have been largely reduced where HR management is used. However, assessments of insect, mollusk, and rodent pest problems and their solutions in conservation systems are

evolving (D. Wirth and D. Glaser, personnel communications, 2004). Nonthermal residue management, including HR management, has other benefits compared with burning of straw. In addition to reduced liability risks, farmers do not need to keep burning crews on standby waiting for regulators to announce allowable weather conditions for burning, and more time is available for nonmarket opportunities including summer leisure activities because farmers do not need to stay on the farm during the burning season (R. Fisher and G. Pugh, personal communications, 2004).

It is anticipated that recent changes in favorable shipping rates to Pacific Rim countries and buyer preference for rice straw will reduce broker demand for PRG and TF straw (R. Fortner, personnel communication, 2004). There is not a suitable livestock feed demand in the region to absorb the level of straw production. Also, shipping costs greatly reduce any potential value return to the farmer as shipping distances increase (Kerstetter and Lyons, 2001). With most growers still preferring to produce their seed crops without straw, a declining market will increase the need for on-farm utilization of straw, and HR management is one option. Other value-added products from straw that may develop include on-farm energy production (Banowetz et al., 2005). In light of the environmental concerns that have driven the demand for change in straw management practices, any alternative uses of straw will have to be considered in light of their environmental impact.

Large-scale use of DS establishment of PRG and TF has just begun to emerge by early adapters in western Oregon on approximately 6000 ha (D. Goracke, personal communication, 2004). New-generation direct seed drills, not available in the early 1990s when this research was begun, are being used (B. Rudenclaw and B. Glaser, personal communications, 2004), as well as custom-made units better suited for planting light-weight grass seeds (D. Wirth and D. Goracke, personal communications, 2004). The primary motivations for adoption of DS are reduced fuel costs for crop establishment, reduced purchased labor costs, and less time required for field preparation. This has also increased nonmarket opportunities including personal time for family activities such as coaching children's sports teams and summertime vacations (D. Goracke and G. Mulkey, personal communications, 2004). It is anticipated that when new tractors need to be purchased, fewer horsepower units will be acquired (existing equipment will not be replaced) (G. Mulkey, personal communication, 2004).

As with HR management, questions have been raised regarding the impact of DS establishment on slug (*Deroceras reticulatum* and *D. laeve*) and gray-tailed vole (*Microtus canicaudus*) populations, particularly in autumn-seeded PRG fields. During the PRG establishment year, slug populations are greater with DS than CT (unpublished data, 2005). Vole activity is also greater in direct-seeded than CT established fields (unpublished data, 2005). The impacts of rotation crop herbicide carryover are another family of concerns. Maintaining genetic purity when changing to a different cultivar in a continuous grass seed crop rotations may also be

problematic because shattered seeds can germinate and contaminate the newly planted cultivar (Young and Youngberg, 1996b).

CONCLUSIONS

These findings describe the suitability of DS establishment used in combination with HR management in perennial grass seed cropping systems compared with benchmark practices that include CT establishment with postharvest residue removed from fields by baling. This information provides farmers and conservation planners alternative economic conservation options with cost savings for PRG, TF, and CRF of 60, 76, and 84%, respectively, using HR combined with DS compared with LR management plus CT establishment. Perennial ryegrass and TF seed yields also were increased using DS. In addition to being economical, HR management and DS can enhance natural resource quality through reduced erosion. Compared with the industry CT-LR standard practices, use of the DS-HR conservation system was estimated to reduce soil erosion 76.9, 70.2, and 40.0% for PRG, TF, and CRF, respectively. There were also non-market valued benefits to farmers using the conservation practices including increased recreation time. These practices are being implemented at the whole-field scale by perennial grass seed growers in the maritime Pacific Northwest region and are beginning to contribute to whole-farm viability. As USDA Farm Bill conservation programs expand and payments become available to perennial grass seed growers, grower preference for DS and HR management may further increase.

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